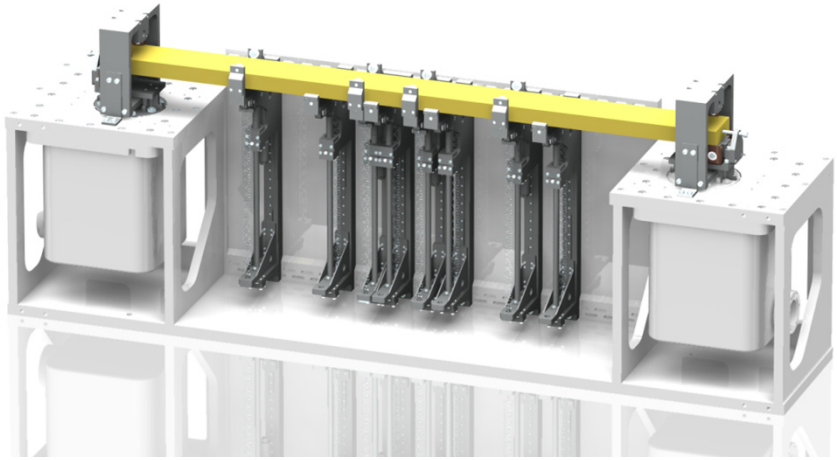
The Nanobender: a New X-Ray Mirror Bender with Nanometer Figure Correction

Carles Colldelram[1], Josep Nicolas[2], Claude Ruget[1]
Llibert Ribo[1], Albert Tomàs[3], Carlos Martín-Nuño[3],
David Úbeda[3]
1. ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain
2. SLAC national accelerator laboratory, Menlo Park, United States
3. Sener Ingenieria y Sistemas, Cerdanyola del Vallès, Barcelona, Spain



Summary

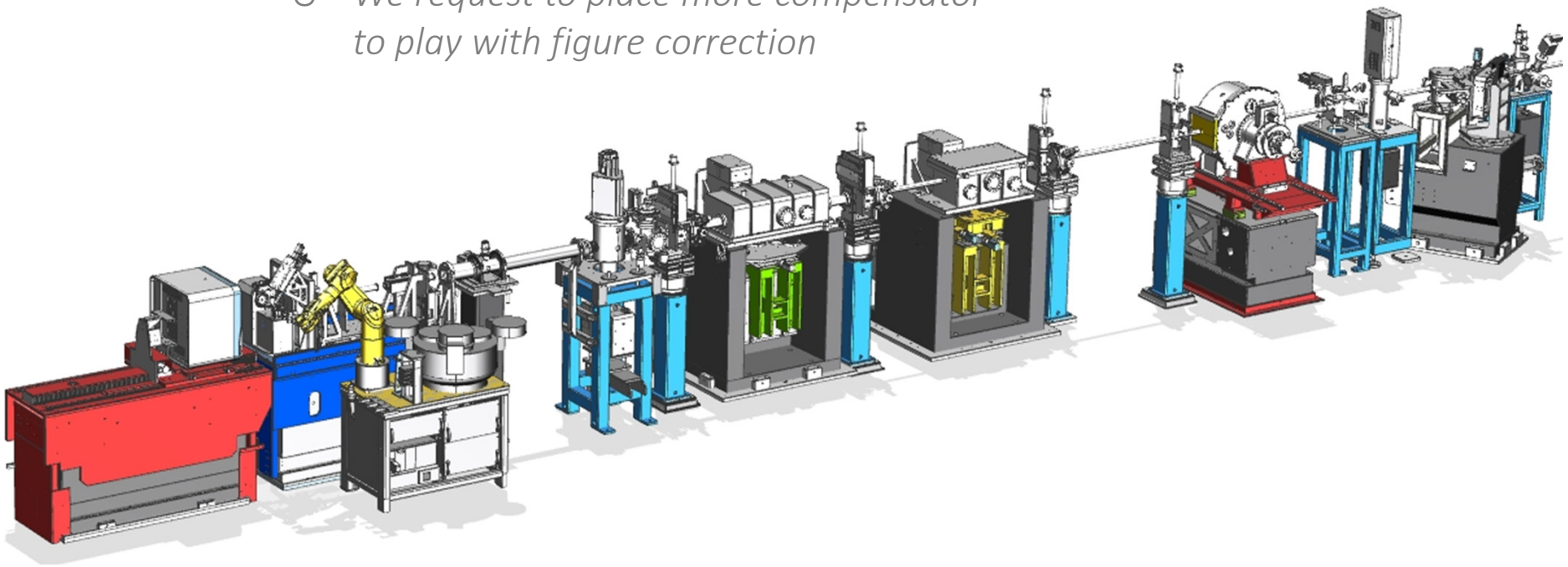
Presentation Summary

- *Precedents*
- *New concepts*
- *Bender design*
- *Correctors design*
- *Construction*
- *Measurements & Results*
- *Next Steps*
  - *Active Optics*
- *Conclusions*

Precedents

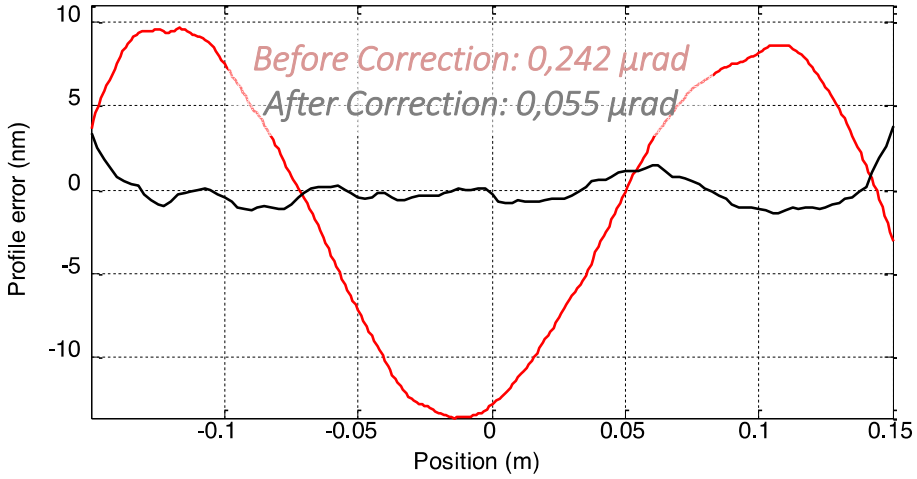
ALBA BL13 Beam Line

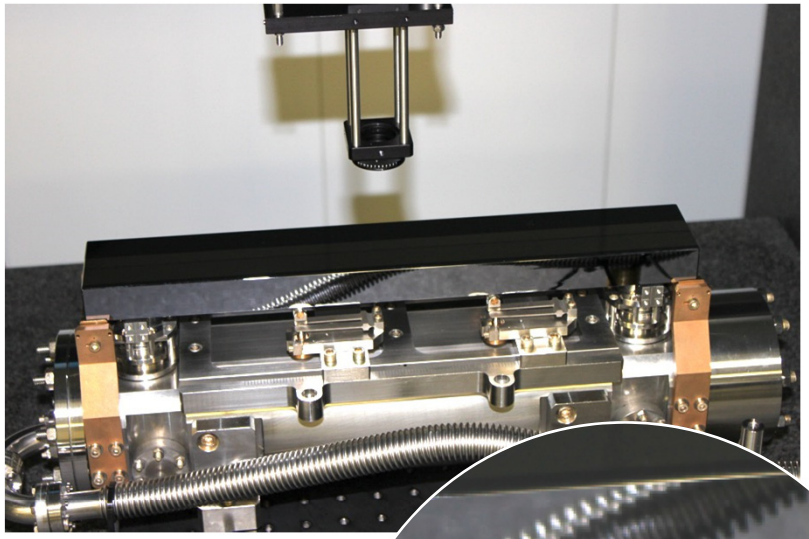
- *Protein Crystallography Beam Line*
- *Vertical Focusing Mirror: Outsourced*
  - *Include a Gravity compensators*
  - *We request to place more compensator to play with figure correction*



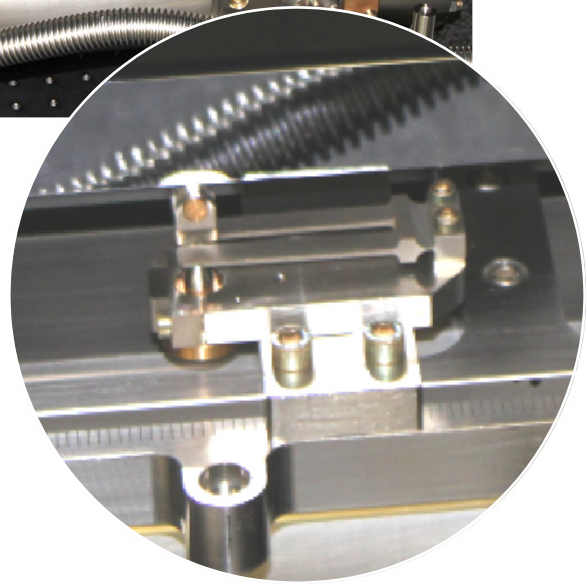
Precedents 2010

BL13 VFM Optimization





Mirror by Insync
Bender by Irelec



- *We corrected the slope error by means the gravity compensators*
- *Optimization of the compensators position*
- *Manual compensators*
- *This compensators are not thought for this function: not friendly adjustment*

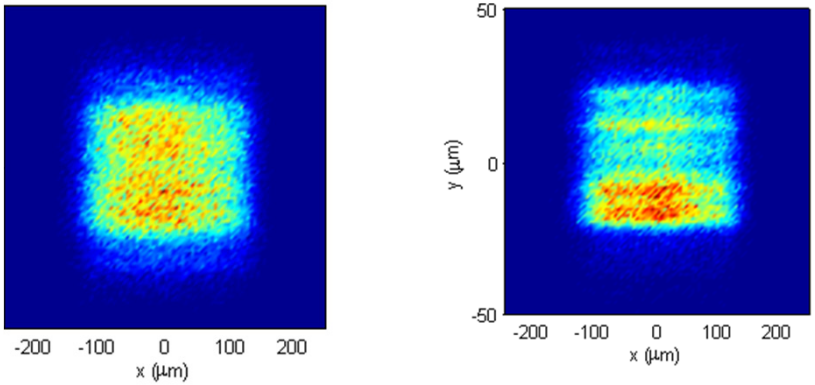
This 300 mm long mirror was optimized from 0,242 µrad to 0,055 µrad

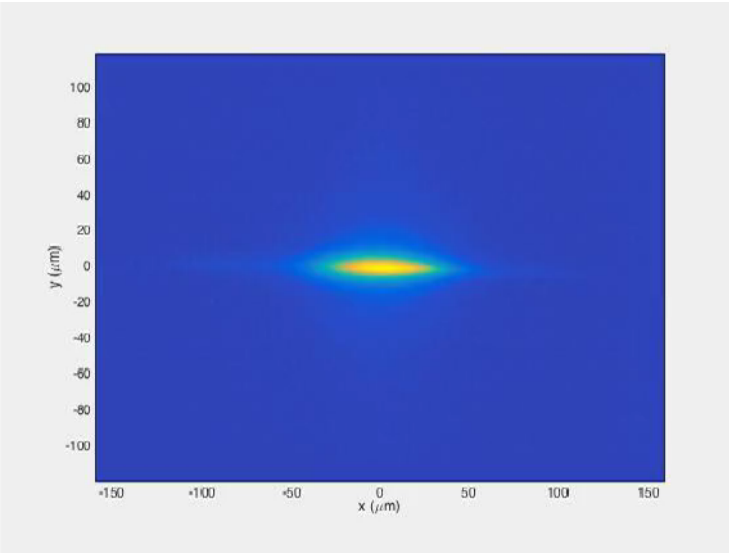
By means two of the gravity compensators both pushing from below

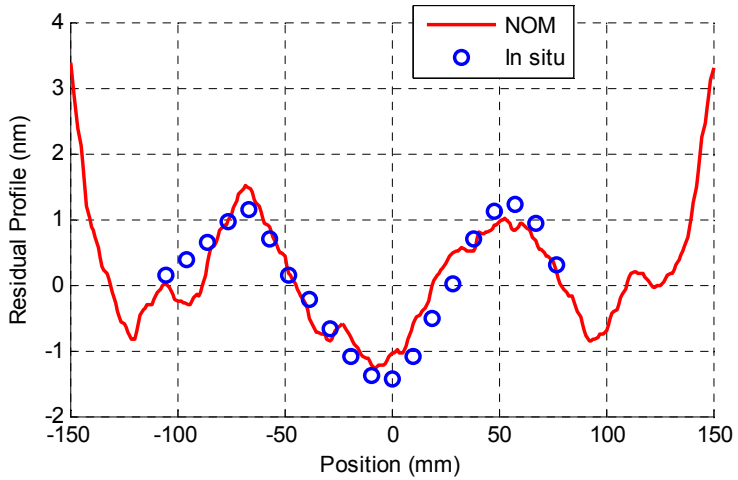
Precedents 2012

BL13 VFM In-Situ measurement

The simulation of the beam by means ray-tracing with the measured corrected mirror figure





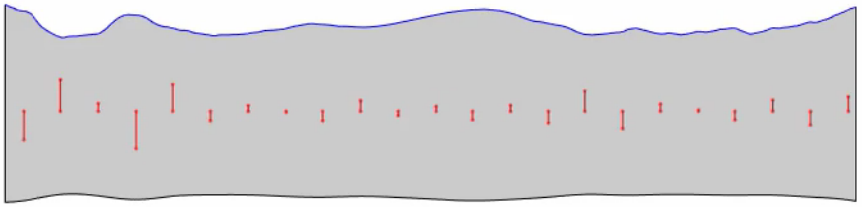


In-Situ measurement after 2 years agrees with the laboratory optimization and measurement

New concepts

Geometrical vs Force constrains

Optical surface with slope error



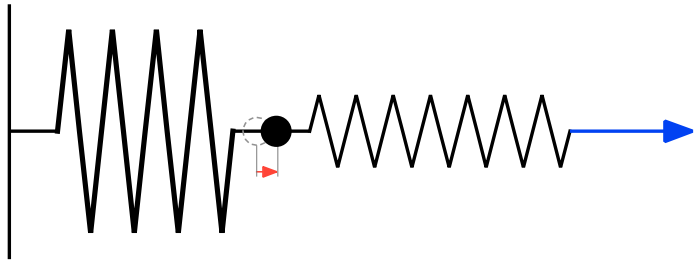
Applied Forces

The hard way

By means Rigid mechanics which introduce the required deformation

vs

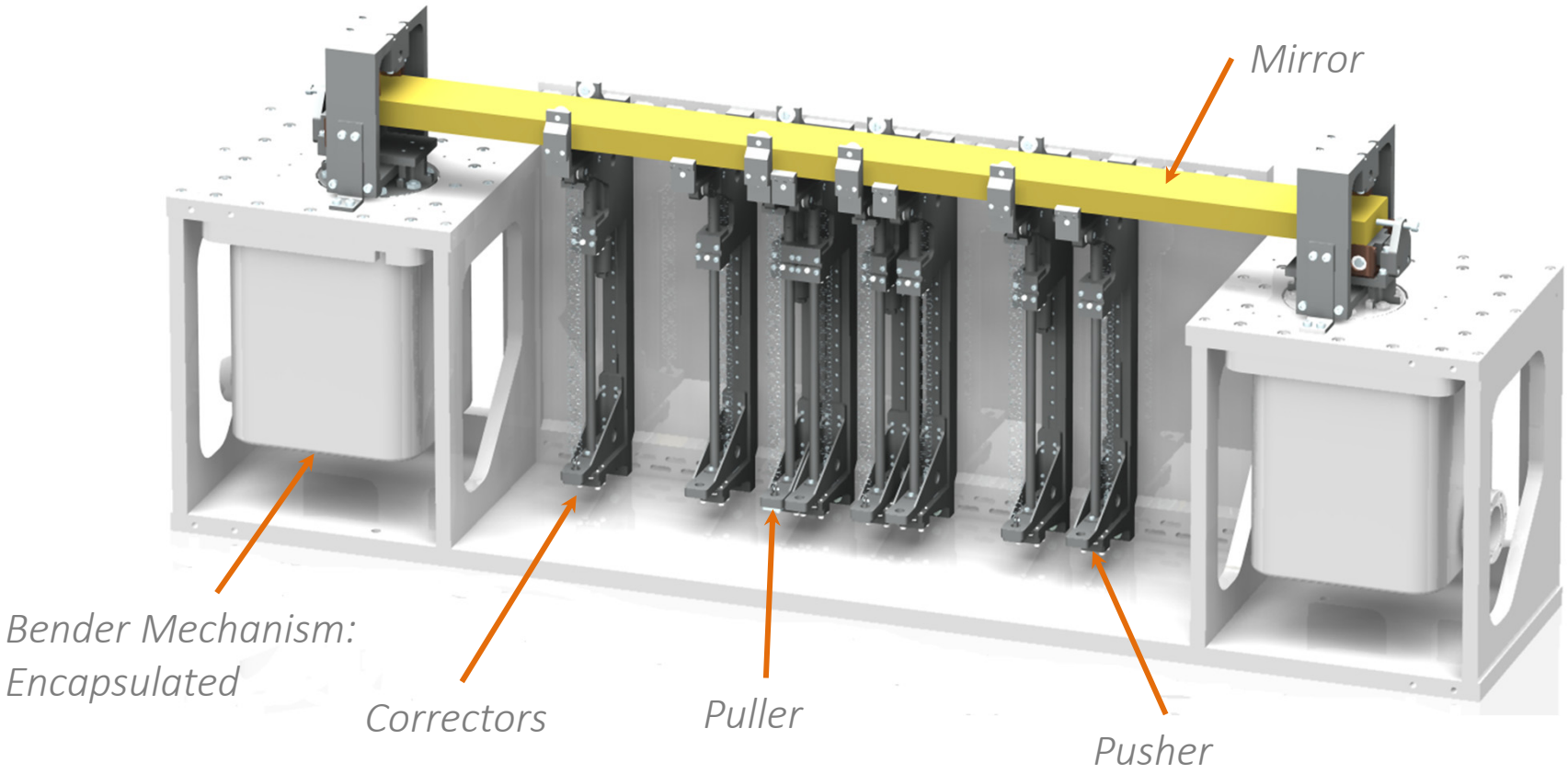
The soft way



…By means of stable-force actuators”

Bender design

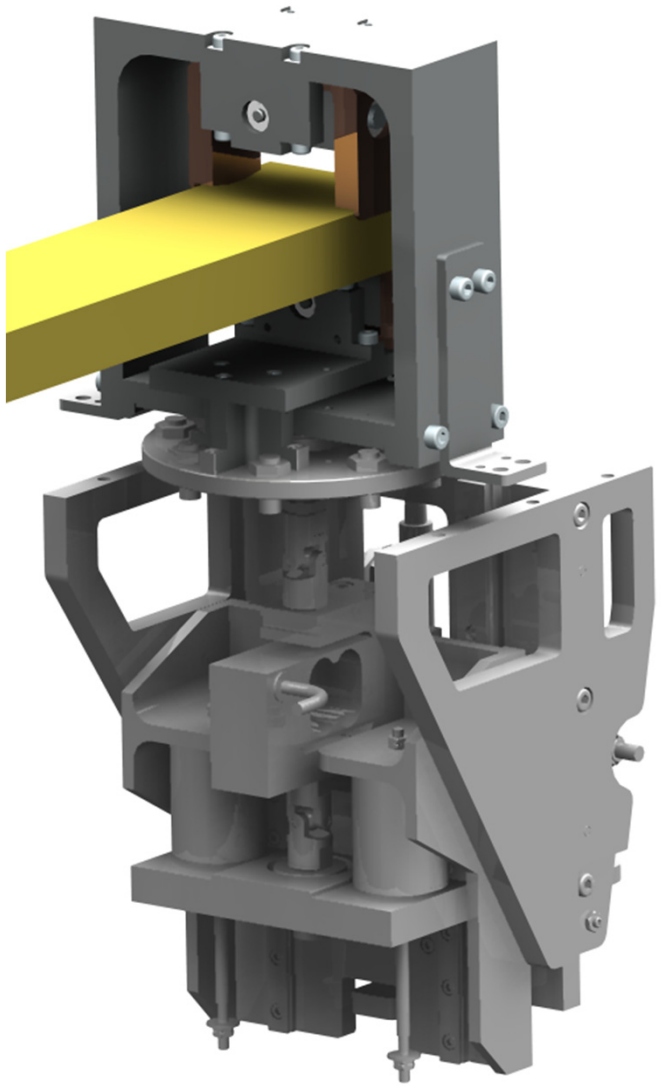
Lay-out



Bender design

Bender Mechanism

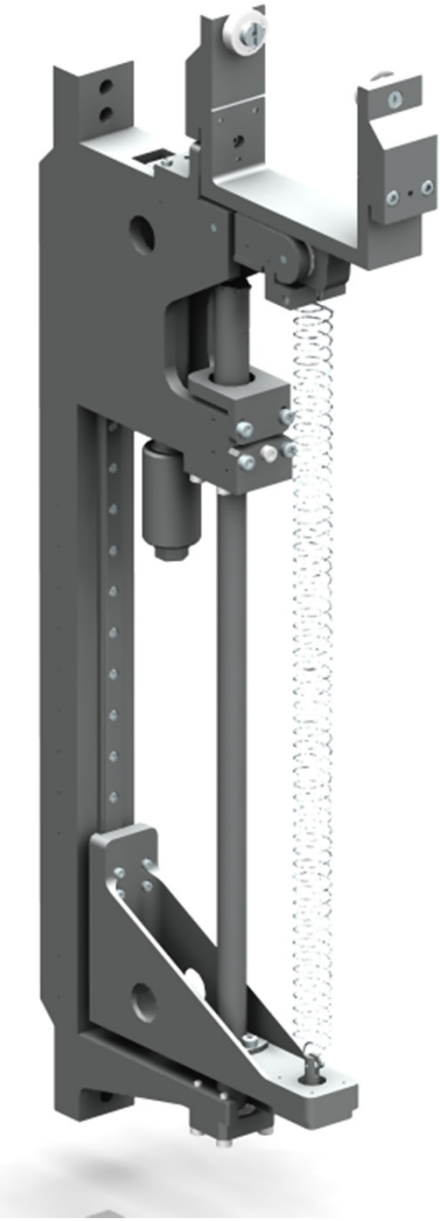
- *Based on compression springs*
- *Convectional motion system for the compression Range*
- *Force gauge measurement*
- *Off-axis relieving Force transmission*
- *Punctual contacts*
- *Flexion at 25 mm from the support*
- *Radius of curvature: 500 m*
- *Forces up to 500 N*
- *Force Resolution: 0,001 N*
- *Focus independent of figure correction*



Bender design

The correctors

- *22 mm width*
- *High resolution force correctors*
- *Ultra low k springs*
- *Forces up to 40 N, ±20 N.*
- *Resolution up to 0,001 N*
- *High stability:*
  - *Independent to the set curvature, no crosstalk*
- *No parasitic torsions*
- *UHV compatible (adaptive optics)*

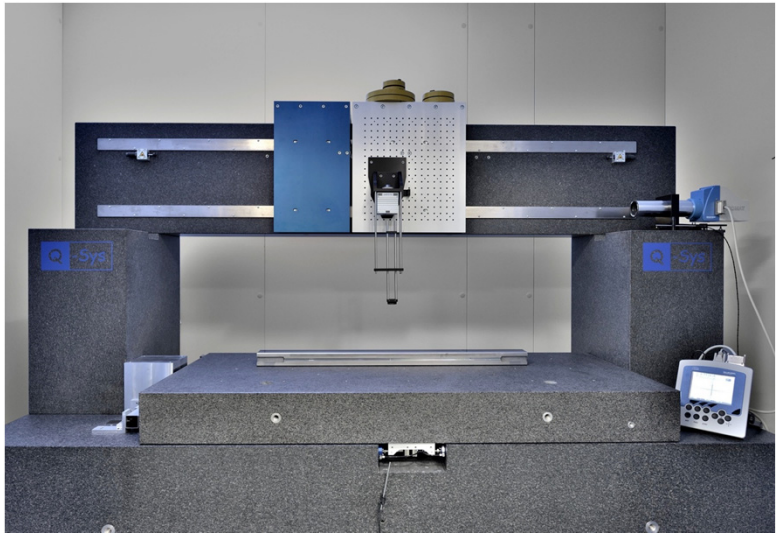


Construction

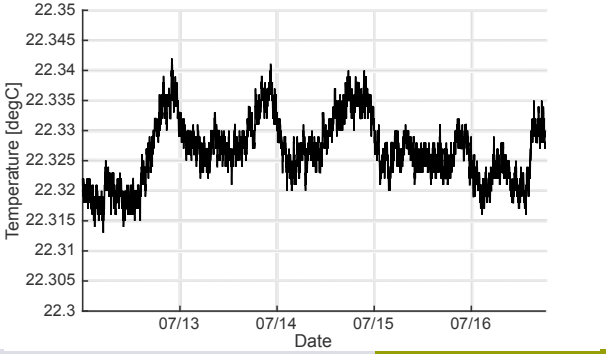
Measurements & results

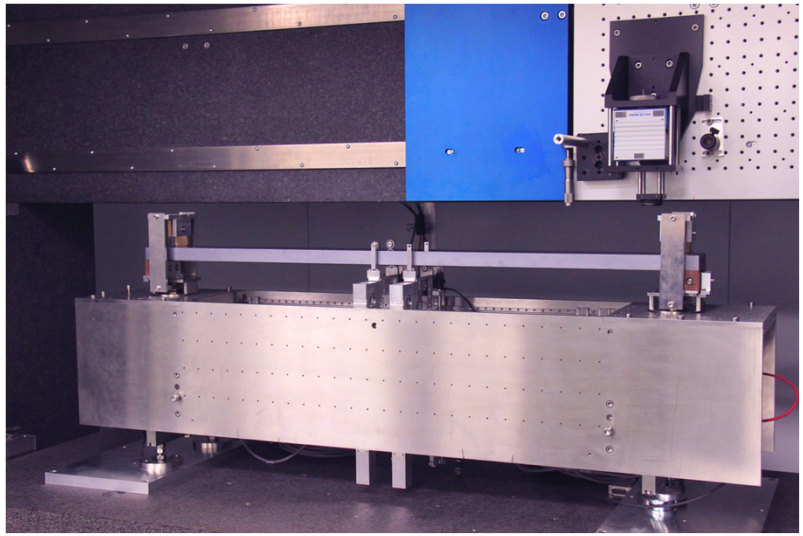
ALBA NOM

- *This is a 1,5 m long highly accurate scanning deflectometer by air bearings*
- *Ironless linear motor*
- *Optical set-up*
  - *Autocolimator*
  - *Pentaprism*



The laboratory temperature is stabilized by means of a PID controlled post-heating system





Measurements & results

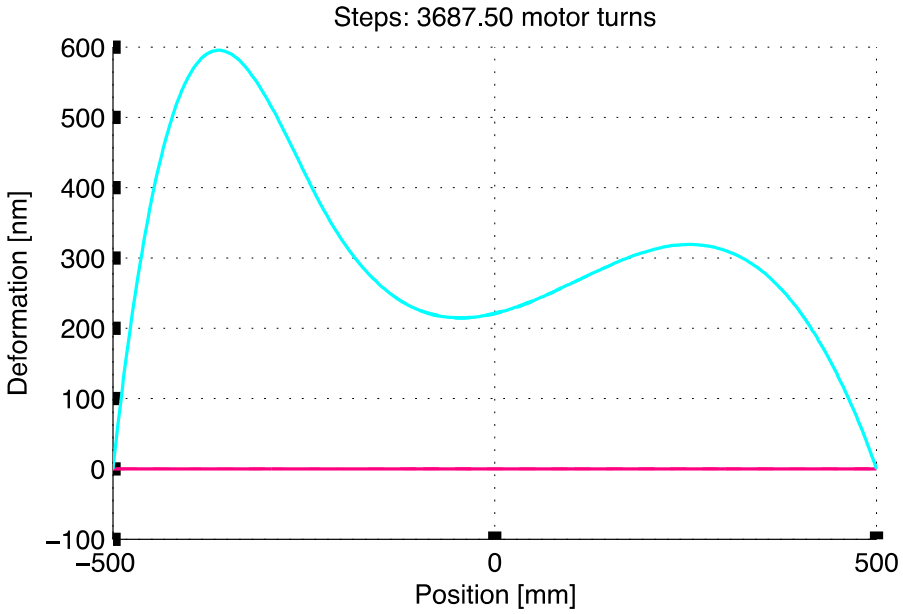
Mathematical deformation Model

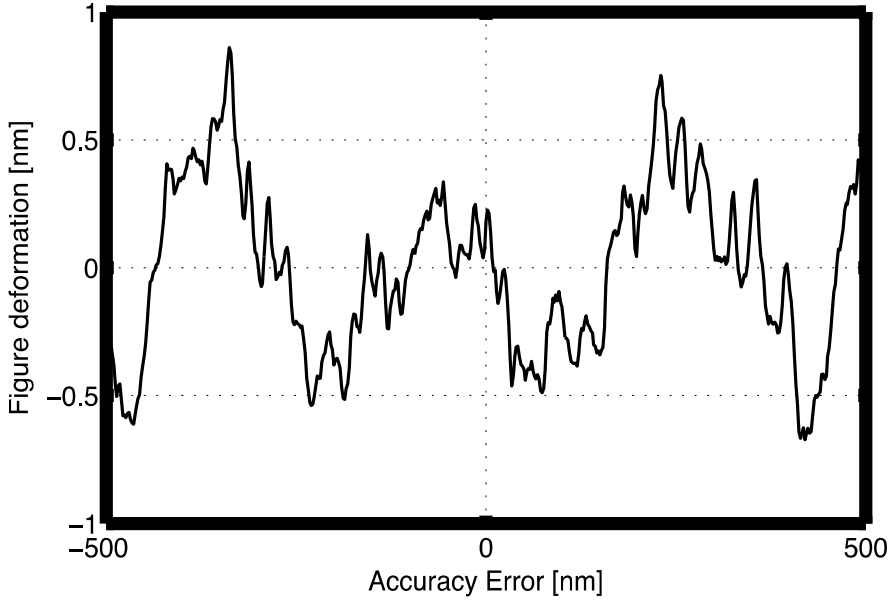
Euler – Bernoulli law

$$EI\frac{d^4}{dx^4}z(x) = \sum_{n=1}^{N} F_n\,\delta(x - x_n)$$

- *LINEAR model, allows superposition*
- *Curvature of deformation is a piecewise linear function*
- *Surface deformation is a piecewise cubic polynomial*

For an induced deformation of >600 nm after removing curvature, the model is accuarate below 1 nm

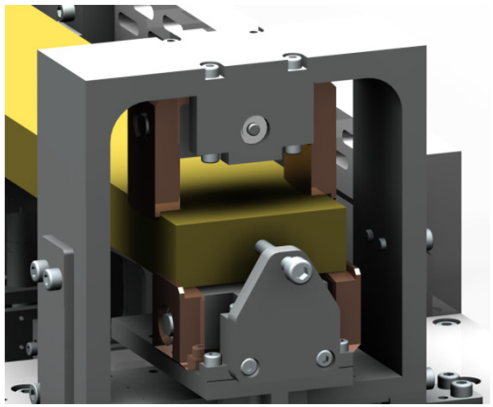


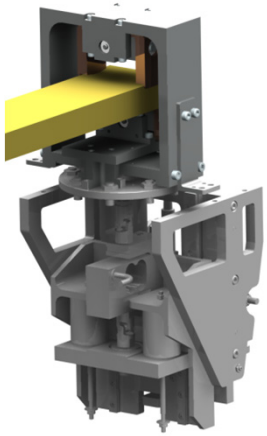


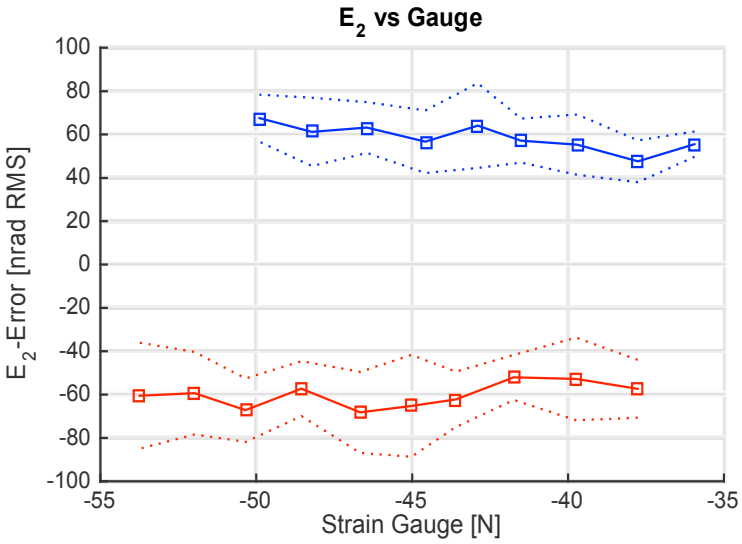
Measurements & results

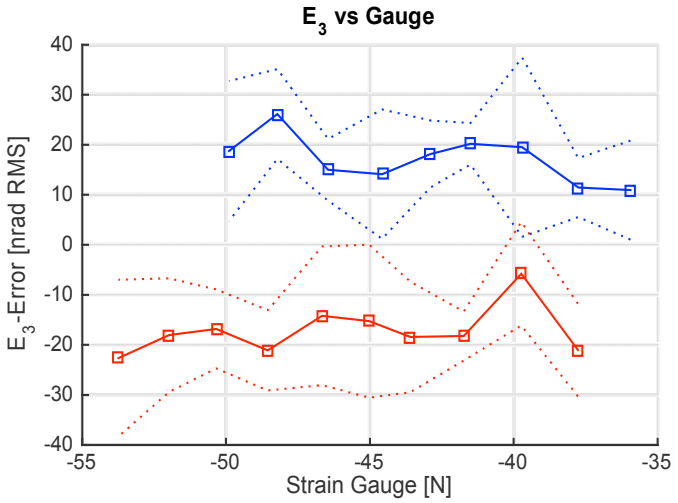
Bending performance

Performance	Figure
Bending range	0-500 N
Bending resolution	<0.001 N
Strain gauge sensitivity	16 nrad rms
Actuator linearity	35 nrad
Bending repeatability	15 nrad rms
Stability	<15nrad/5days







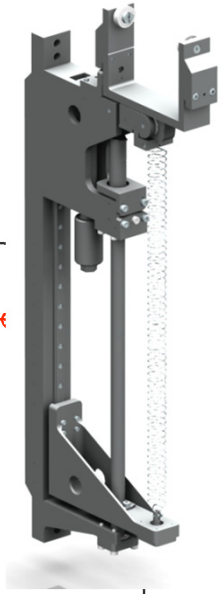


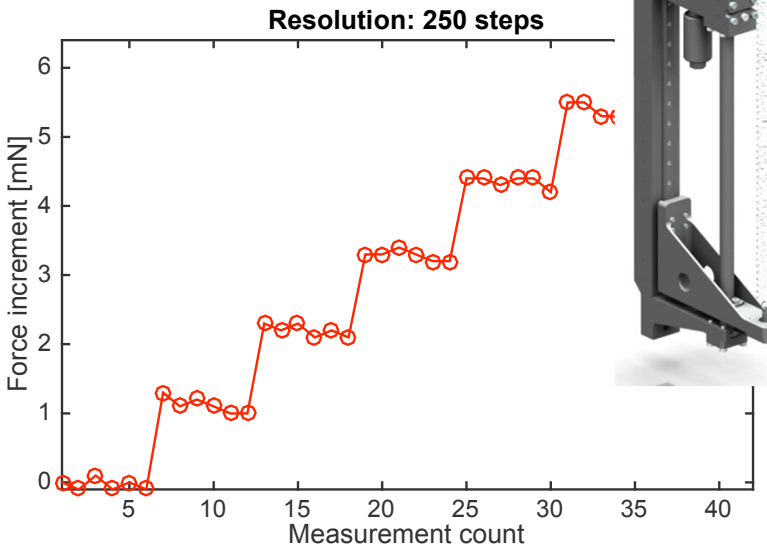
Measurements & results

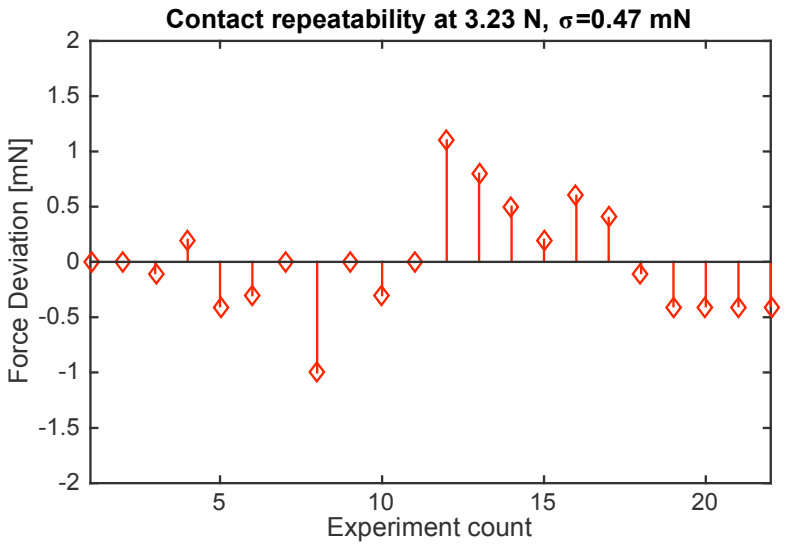
Correctors performance

Resolution of 0.001N allows sub nanometer correction, as well as stability

20 N is the force estimated to correct 0.5 µrad rms mirrors for errors with period down to 22 mm



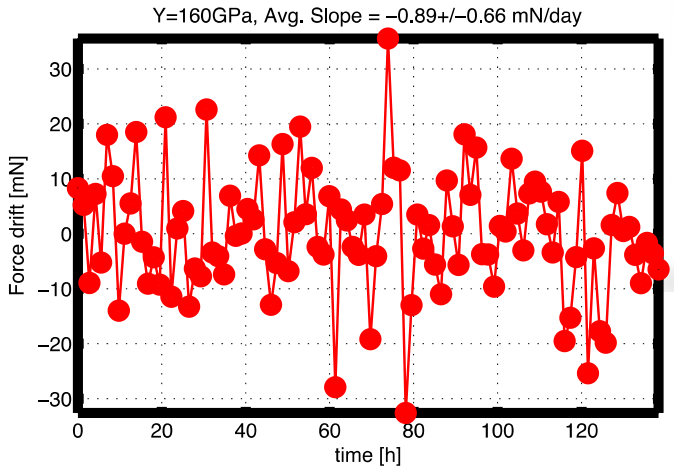




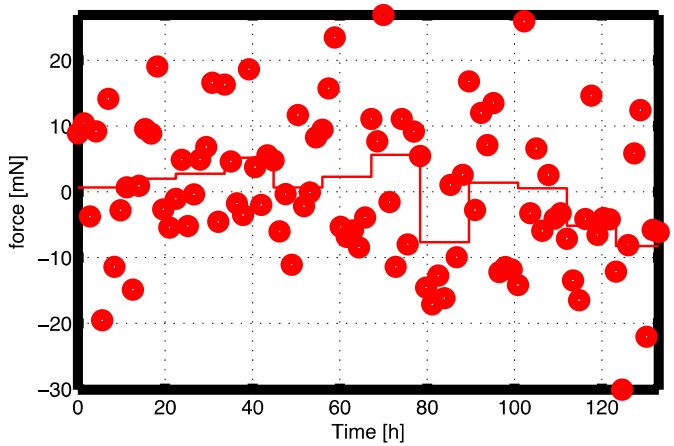
Measurements & results

Correctors performance

Stability for 130h



Repeatability on recovering a position between motions to random points

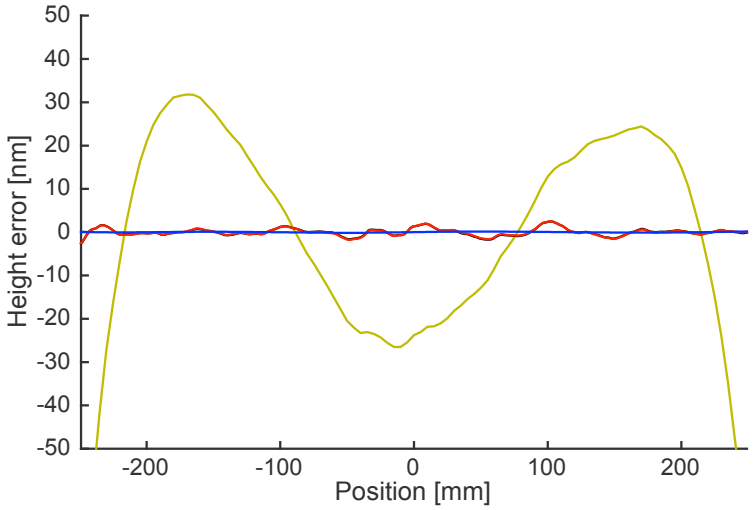


Measurements & results

Mirror Optimization

Initial slope error: *0,87 µrad RMS*
Corrected slope error: *0,115 µrad RMS*

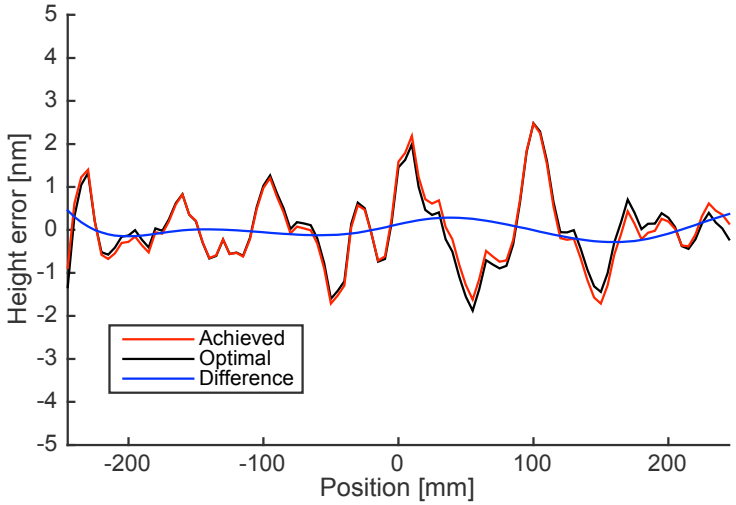
Initial surface error: *23,2 nm RMS*
Corrected surface error: *0,858 nm RMS*



The mathematical model:

- *Optimizes the correctors position*
- *Optimizes the corrector force (and its sense)*

The model predicts the deformation of the mirror with accuracy better than 0.08 nm RMS

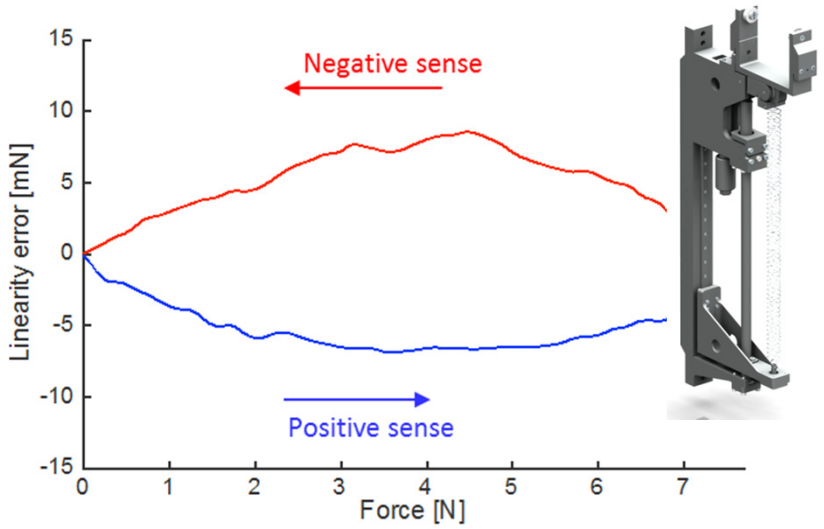


Next steps

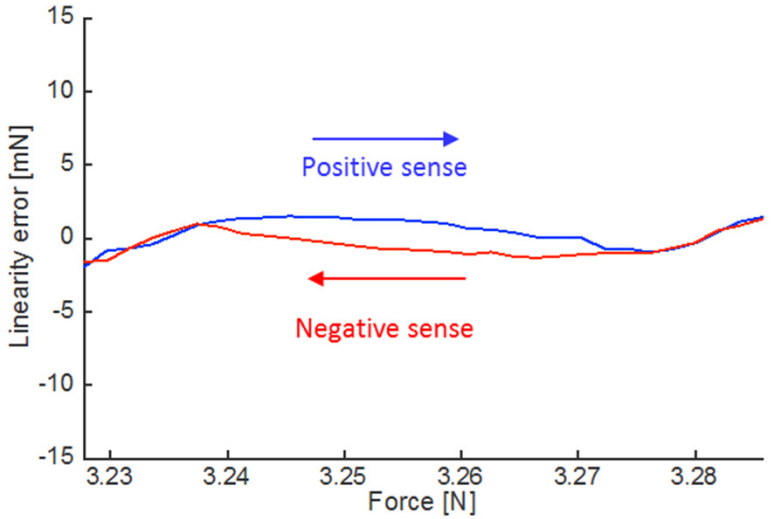
Corrector Improvements

- *Corrector Repeatability: Done*
- *Remove the bender mechanics encapsulation*
- *Compact the bender mechanism*
- *Compact the correctors*

Repeatability Long Range

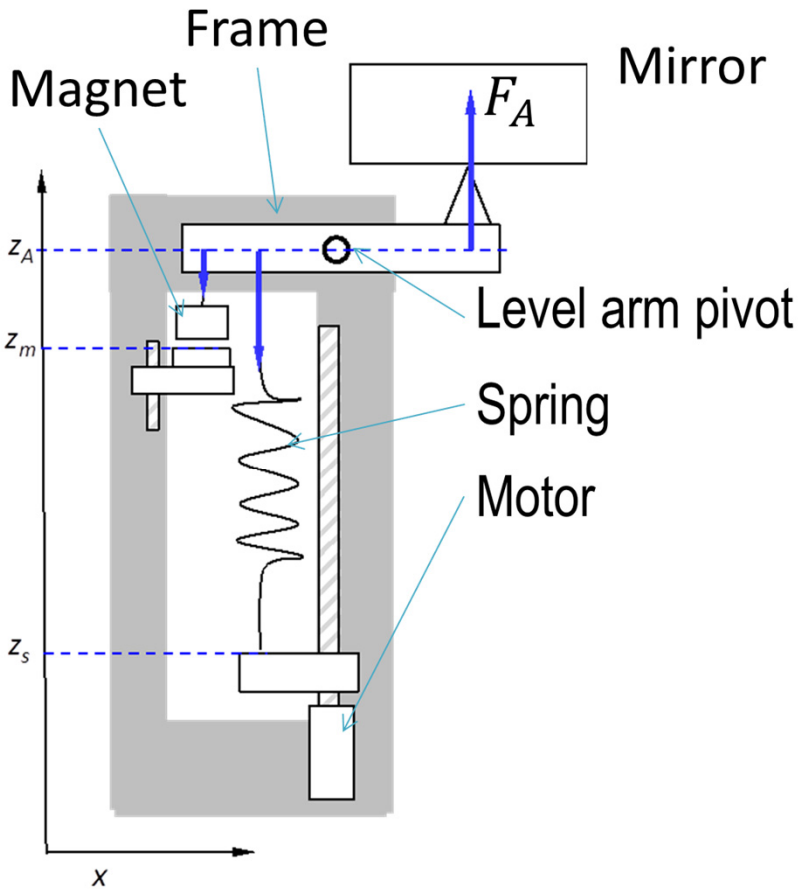


Repeatability Short Range

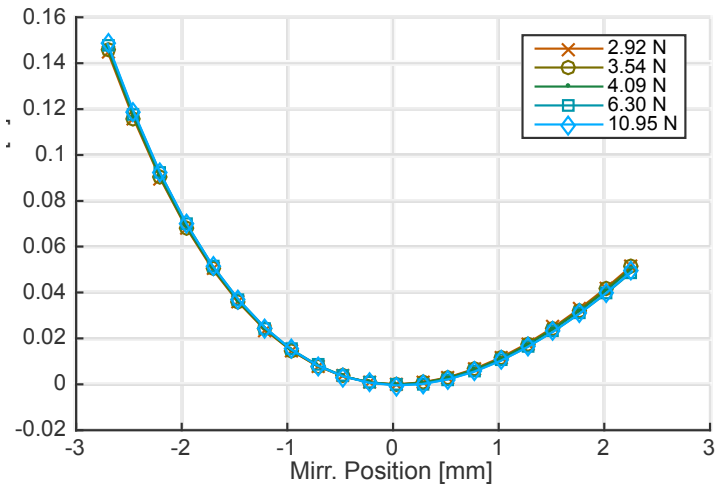


Next steps

Corrector Improvements



- *-k magnet system for spring k compensation*
- *Insensibility to magnet position in a ±1 mm*



Next steps

Corrector Improvements

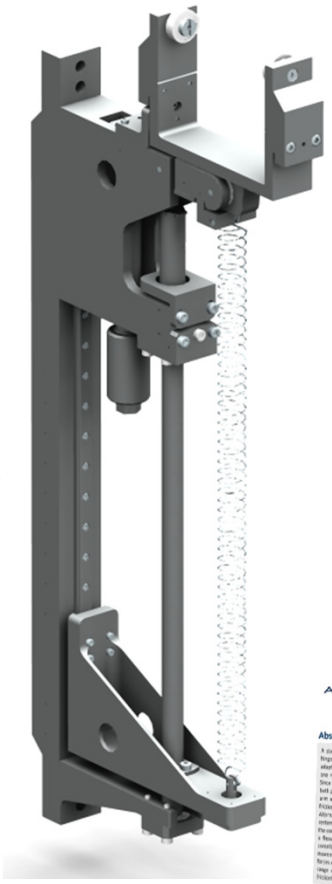
To be implemented soon

- *Spring length reduction by means the force compensation system:*
  - *Test prototype done and measured.*
  - *-k spring with magnet.*

- *Removal of the bearing friction on the spring articulation:*
  - *Test prototype done*
  - *Zero-torque frictionless articulation*
  - *By means a flexure and magnet system*

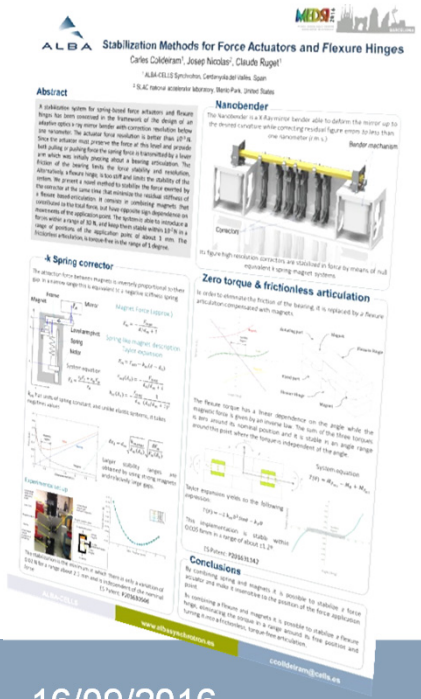
See the poster :

ID: 2029 - MOPE01 Stabilization Methods for Force Actuators and Flexures



Three patens

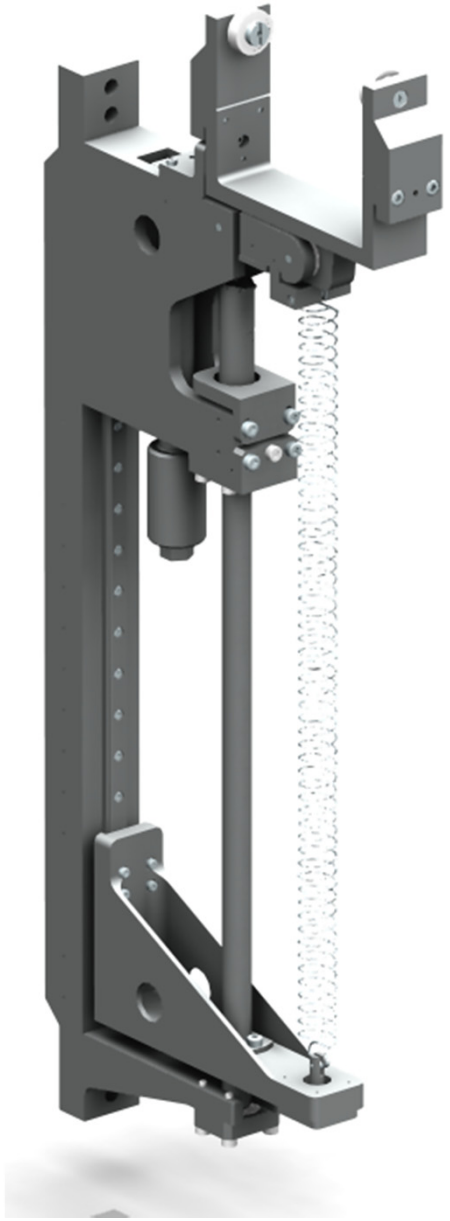
ES P201631142
ES P201630506
ES P201530735



Next steps

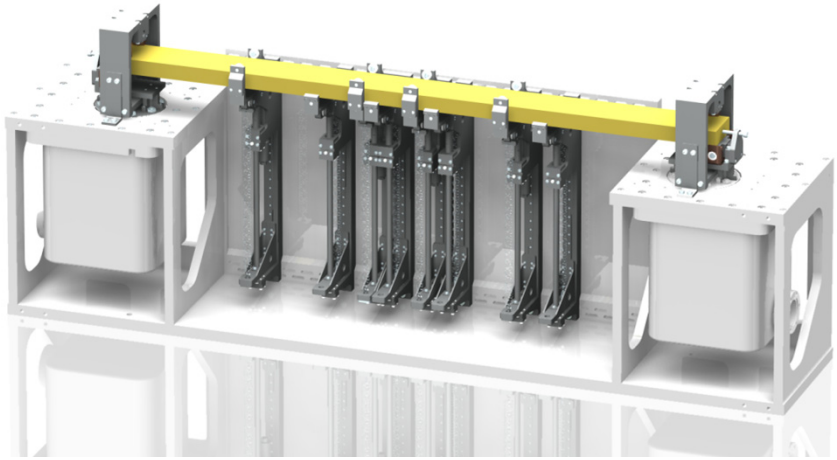
Active Optics

- *With such figure error accuracy and resolution it is possible to correct beam wavefront distortions*
- *With a double spring the corrector can switch from pusher to puller just by moving along the range.*
- *Change the Stepper motor for a UHV compatible one.*
- *mount as many correctors as space allows.*



Conclusions

- The proposed solution of a bender with figure correctors based in force constrains works at nanometer level
- A mirror bender with correctors without crosstalk is achieved.
- A very stable correctors have been design and implemented.
- New –k compensated correctors have been designed and tested. They keep force constant within 1 mN in a range of motion of the mirror up to 2 mm.
- New, frictionless, torque free articulation has been designed, and is being currently tested.



Acknowledgments

Joan Casas

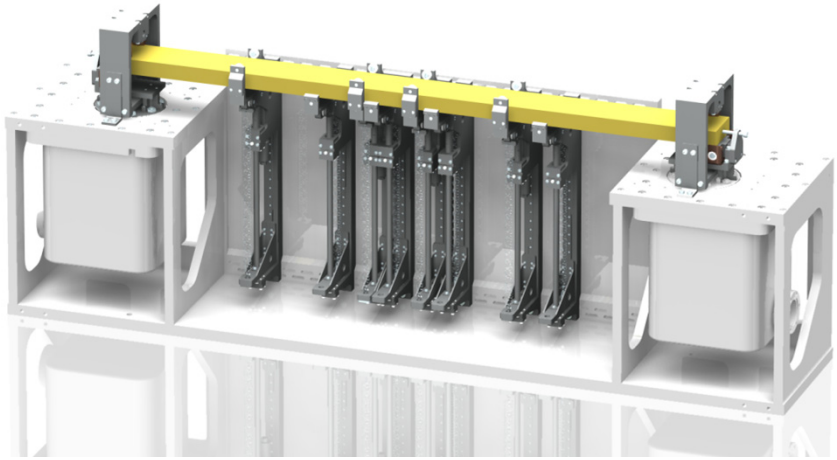
Jose Ferrer

Gabriel Peña

Llibert Ribó

Pablo Pedreira

...



Thanks for your attention …